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brittle fracture is obtained and the greater the probability of its appearance.

In following the ideas developed by Davidenkov and Fridman, one or the other form of fracture of cold-short metal must be assumed to depend upon various causes. If the original cause of the dull fibrous fracture lies in distortions created by a shear-like plastic deformation and the break takes place as a result of the attainment of (a) "a ductile stability" (according to Davidenkov) or (b) a critical value of shearing stress (according to Fridman), then a brittle fracture appears after the attainment of a "brittle stability" by normal stress action. Thus, specific mechanisms and criteria of a fracture adapt themselves to every fracture type.

The main proof of the authors in favor of this concept is based on the distinct external difference in the two types of fracture and the almost imperceptible transition from one to the other. Another basic proof involves the results of determining the strength of a specimen with various notches. These experiments took place during Kuntze's (6) time. The results of these investigations led to the conclusion that the strength of the notched specimens grows with increase in sharpness of the groove and that the plastic deformation acquired by the specimen up to the fracture decreases. Davidenkov sees in this a description demonstration of the fact that: 1) a definite "tensile strength" exists, varying with the change in form of the notch and that: 2) a limited plastic deformation, preceding the fracture, depends on the form of the strained state.

Another point of view may be seen in Kuntze's individual

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expressions, most clearly expressed by Yakutovich and quite recently superficially mentioned by Orovan.(7)

This concept first asserts that almost any break takes place by normal stress action, during which its indication in some cases (a crystalline break) has a clear and unconditional character, and in other (fibrous breaks) has an unclear and, hence, doubtful character, initially.

In defense of the latter theory, there is still no definite experimental evidence and the proofs of its authors are built on general considerations and intuitive predictions, at times not very reliable.

Orovan's proof, for example, as proposed by him to refute the ideas of Davidenkov and Fridman about the existence of two branches in the strength diagram (that is, against the theory of brittle-ductile stability) disregards the fact that during stretching so many more plastic deformations are obtained (several 100%) that they in no way fit into the framework of Davidenkov and Fridman's theory, therefore Orovan's proof should not be admitted as something serious and convincing. Actually, two completely different strained states are compared which give completely different macroscopic maximum characters of plasticity and strength, evolving from both theories of fracture of metals. The maximum characteristics for the micro-volumetric metal are probably identical for any load conditions.

Nevertheless, it seems to us that sufficiently weightly and convincing arguments of a theoretical and experimental can be presented in favor of the second theory of normal strength (which the author of this article supports).

First, we shall ~~give~~ write a few words about the form of the notch itself and the microscopic picture of fracture.

As already pointed out, Kuntze noted that fractures across the shear planes, i. e., across the planes strongly distorted during the deformation process, should have a unique character.

A microscopic picture of such a fracture presents a certain resemblance to a ladder with small steps (Figure 1). The steps are those areas of weakness in which the fracture properly takes place; that is, the break is due to normal stress action and the first disturbances in the continuity of the metal is formed. Carrying out a certain analogy of metal with wood, Kuntze cites the fracture of wood to illustrate such a type of fracture. The steps in the fracture of wood are of macroscopic form and therefore are easily observed by the eye.

Metals fracture across the plane of slipping (badly damaged) with the help of such a mechanism, but with the formation of very small 'micro-steps'. Due to this minuteness of the steps, visual examination of the fracture does not permit one to detect its structural peculiarities and therefore the external apparent picture has the appearance of a fracture taking place by the action of shearing stress by notching.

An apparatus of considerable power, if applied to this problem, should sooner or later reveal the stepped or terrace-like microstructure of a ductile fracture.

Another indication also supports the concept of one single mechanism of fracture in metals and evolves from data on the microscopy of the process. Rebinder(8) on the basis of experiments which are conclusive and direct, shows that any shear, even quite small, causes disturbances in continuityand micropores, probably along the boundaries of the slipping. Such "fracturings" and ruptures in ductile fractures are difficult to substantiate shearing stress action. Indeed, it is not understood how an initial small displacement accompanied by a slight deviation of atoms of adjacent layers can lead to ruptures. At the same time the assumption about the weakening of connection and the disturbances in stability during displacement appears to be completely possible and logical; the addition of normal stress in sufficient degree at this moment can cause free surfaces and microfractures. Thus, the theory of normal strength in this case also leads to a clearer and more logical solution.

We shall turn now to the macroscopic picture of fracture and then to the corresponding diagram of strength.

A proof in favor of the theory of brittle-ductile stability is the assertion of its supporters that the ductile fracture during distortion always takes place perpendicular to the axis of the specimen; i. e., as if under the influence of shearing stress. However, it is not difficult to show that this assertion is groundless.

It is a well-known fact that fracture from fatigue is connected with the flow of the previous local plastic deformation and therefore that this type of fracture would seem in any case necessarily to be due to tangential strain action. At the same time it is a well-known fact that fractures of fatigue frequently occur at an angle of 45° towards the axis of the specimen; i. e., longitudinally to the line of action of the greatest normal

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strains. What is more, the fracture of fatigue, beginning under the 45° angle towards the axis, often continues to develop along the axis; i. e., longitudinally to the line of action τ_{max}.

The described two-stepped process of plastic fracture during distortion and the transition from one orientation relative to the axis to another for the same specimen prove to be incomprehensible from the point of view of the theory of brittle-ductile stability, but easily explains the theory of single strength, being a graphic confirmation of its accuracy.

Indeed, from the point of view of a single strength of fracture, plastic deformation is always preceded by an accumulation of distortions and is completed with the deterioration of normal stresses. The causes of fracture are undoubtedly connected with normal stresses in the above-stated cases. The change in macro-orientation of the fracture should be related to the magnitude of plastic deformations, leading up to the fracture. Namely, at the beginning of fracture, when the general plastic deformation is relatively small and the boundary distortions of the lattice are reached in relatively small numbers of portions of the specimen, the fracture occurs longitudinally to the line of normal stress action. Later on, however, with the accumulation of a considerable quantity of plastic deformations and the strengthening of macro-distortions created by it, fracture begins to follow the line of τ_{max}. In the latter case, also, however, the fracture is governed ultimately by the normal stress action and completes itself longitudinally

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to the micro-steps, slanting toward the axis and the line of macro-fracture.

Now about the diagram of strength. Figure 2 is a diagram of strength, describing the dependence of the resistance of break (CD) upon the degree of preliminary cold-hardening, as shown by the curve of true stress or the curve of yield point during tension (AB). The latter curve is obtained in the case of tension under normal conditions(smooth specimen, under static load and at room temperatures). The curve of resistance of the fracture is constructed by a two-step method; namely, the specimen of the examined metal is first brought to the indicated degree of cold-hardening for the same normal conditions as in the curve of maximum viscosity, and then it is submitted to loading under special conditions contributing to full retardation and exclusion of plastic deformations, most often by cooling the specimen to the temperature of liquid air.

The plan shown in Figure 2 agrees in general with both theories of strength. The principle difference in these theories is discovered only upon examining the final stages in the diagram; i. e., at those degrees of cold-hardening approaching the largest cold-hardening attained on the curve AB at the moment of fracture (point B).

The theory of single (normal) strength of the curve assumes that direct linear resistance to fracture CD virtually exists in the whole range of plastic deformation, corresponding to the curve of stress (AB); namely, that there is a point D describing the strength during reduction in area $\varphi = \varphi_0$, i. e., reduction in area during ordinary rupture at point B (curve AB). Or still differently: it is considered that the virtual fracture at point B takes place under stress ED, (Figure 3), notwithstanding that in the experiment we fix the value of strength EB. The latter value should be recognized as basic.

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The theory of brittle-ductile strength and the existence of line D_1B, are confirmed by the results of experiments with fractures of still more severely (of sharper groove) cut specimens. As already indicated, curves of type D_1B are actually obtained.

The latter experimental fact will be shown not to be a convincing argument in favor of the theory of brittle-ductile strengths.

The following was shown in our experiments,(9) which included establishing and contrasting linear resistance to fracture and diagrams of true stresses (yield strength), taken at decreasing temperatures. The breaks in the diagram of yield strength for various temperatures and sharpnesses of the notch are in accordance with the curve D_1B; the parameter of temperature and notch behave similarly in this sense. However, the measurement of the strength of specimens which received various preliminary plastic deformations at room temperature and then were broken at -196°C., leads to another result. It appears that points describing the strength of specimens with the greatest cold-hardening--down to point B lie at distance D_1D and appear as a part of curve CD, and not curve D_1B. As was demonstrated in these experiments, more premature breaks in diagrams of true stress, at decreasing temperatures leading to the appearance of line D_1B, are governed by the below-mentioned description of the fracture in specimens with 'neck' or 'waist'.

As is known,(11) the fracture of a specimen with a 'waist' begins at the center. During a decrease in temperature, the

the action of a central crack playing the role of an inner notch becomes more effective (due to the simultaneous action of the temperature) and leads to cold-shortness. Due to this, the outer ring-rim surrounding the region of the central crack (primary rupture) fractures according to the type of macro-break, upon reaching curve CD, and a shining brittle area is formed. The relative decrease in plastic deformation of the reduction in area and the approach towards point D take place at relatively greater decrements in temperature; i. e., during the more active reaction of temperature upon metal. Corresponding to this, the ratio of the areas, occupied by the shining ring and dull 'eye' continuously changes; the first grows more and more and the second contracts, crowding towards the center until it disappears entirely (at this moment the level of the curve CD at point D_1 is reached). Thus, the curve D_1B is not a physical phenomenon, but reflects the peculiarities of the geometry of the break and only shows the degree of prematurity of the break in relation to maximum deformation as determined by line ED. The physical strength is described by the curve CD. In other words, the curve D_1B reflects normal strength and D_1D reflects actual strength; the difference in levels of curves D_1B and D_1D for corresponding degrees of cold-hardening is characterized by the coefficient of concentration of internal overstrains.

In the case of notched specimens, we have precisely such a picture. Only here the geometric factor, allowing us to relate the obtained nominal stresses to the true, acts in a more complex and camouflaged manner, due to the complexity of the strained state in the notch, and does not lend itself to simple detection and calculation. However, if we could do this, then we could also obtain a curve of actual strength D_1D for notched specimens.

If we could eliminate the appearance of the 'waist', leading to the above-mentioned heterogeneity of the break, then the curves of true stress would reach straight-line ED. To justify this assertion, we made tests, by taking diagrams of true stress for various temperatures, on materials which were not cold-short (or on cold-short, but which were at relatively high temperatures). Considerable degree of regularity is observed; in agreement with this, fracture takes place for the same maximum plastic deformation characteristic of the given material. Thus, it becomes evident that a dull fibrous fracture takes place from the exhausting of the metal's potentialities toward plastic deformation--from the metal's attainment of maximum plastic deformation; but during an "accidental" stress, i. e., during stress which is determined by conditions of load, temperature, rate and geometry (form of specimen, concentration of stress), it is not connected with the physical substance of the phenomenon of fracture.

In other words, the value of strength obtained for various circumstances in fracture tests (σ_{B}, σ_{B_1}, σ_{B_2}) is clearly conditional and is determined only by the equation of the diagram of true stress for a given temperature or given form of notch. σ_{TD} is a characteristic constant and is the only correct value of strength, responding to reduction . All the remaining intermediate stresses at the moment of break should be recognized as accidental and therefore, from a physical point of view, as conditional.

However, the strength established in the experiment is always the strength shown by line D_1B. Therefore, practically

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all constructive calculations and syntheses can be made according to the data for this strength.

In accordance with this it would be most correct to designate the strength defined by line D_1BB_1 as the technical strength and the line CD_1D as the real physical strength.

Generally speaking, at room temperatures the attainment of maximum plastic deformation is equivalent to the attainment of maximum shearing stress. Therefore, under these conditions it is difficult to establish the true criterion for ductile breaks. However, tests performed at decreasing temperature permit one to separate the influences of these two parameters and to select the actual criterion for ductile breaks. As was shown for decreasing temperatures, fractures take place under various stresses, but for the same magnitude of plastic deformation of 'necking'. Hence it conclusively follows that the criterion determining ductile break is maximum plastic deformation and not maximum shearing stress.

With this it is necessary to turn our attention to the following. Some investigators consider that the contrasting of diagrams of true stress, taken for decreasing temperatures, is not significant, inasmuch as the same material at every new temperature should be examined as new original material. However, such a consideration is unfair. Actually, if the decrease in temperature changes not only the properties but also the structural peculiarities of the given material, then the constancy of plastic deformation of ductile strengths should be completely incomprehensible. It is difficult to realize that the so-called "new" material created by low

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temperatures should be such a guardian, as it were, of its previous 'traditions' and would continue to break always at a strictly constant magnitude of 'necking'.

At room (or other constant) temperatures, however, the criteria of maximum ψ and τ are adequate; therefore a comparative analysis of the various strained states, conducted by Ya. B. Fridman, led him to the conviction about the constancy of τ in all investigated cases. In reality, the equality of maximum plastic deformation occupies a place here. Insofar as in practice it is usually necessary to deal with constant temperature conditions, then the criteria τ are fully correct and, as more convenient, can be drawn fro the fulfillment of necessary calculations, as Fridman proposed.

The ductile fracture for a determined characteristic for a given material degree of plastic deformation will survive only until such time as the geometry of the deformation of the specimen (form of the waist or 'neck') will remain constant. In particular cases of load, for example in uniform hydrostatic compression when the conditions of the macro-process of plastic deformation and waist formation vary, the degree of maximum plastic deformation should change, as was observed by Bridgeman.

It is necessary to note still one more circumstance, that complicates the diagram of strength and leads to the necessity of introducing into it a supplementary superstructure.

As is generally known for metals and solids, there exists a completely specific value of theoretical strength, considerably exceeding the magnitudes of true physical strength obtained in experiments. How should the curve of theoretical strength look in contrast to the examined diagram of strength?

It is sufficiently proven and logical to suggest that the theoretical strength will be greatest for the starting material with an intact structure of crystal lattice. The creation in the specimen of plastic deformation, as small as desired, should lead to weakening in bond or connection, as follows from the ideas of Stepanov (10) and Rebinder (8), and to decreases in theoretical strength. Therefore, the curve of theoretical physical strength as a function of the degree of preliminary cold-hardening should decrease most probably in a fairly intensive manner. (Figure 4)

It can be imagined that during 100% contraction ('necking') the curves of theoretical and true physical strength would intersect, as is shown in Figure 4.

A natural question arises: why, during decreasing temperatures and the blocking of plastic deformations, do we fix the magnitude of strength corresponding to the curve of true and not theoretical physical strength? The answer is clear and simple. The fact is that, before we attain the curve of theoretical strength, which should be governed by the break across the areas, distorted by shearing plastic deformation, we come upon a level of resistance to twinning (varying with cold-hardening) and twins appear in the specimen. The distortions made by the twins prove to be considerably more intensive than those made by shears; therefore in the experiment there is fixed some stress appearing as intermediate between the diagram of true stress and theoretical strength.

There is also another question which can be asked in connection with the problem stated, namely: why does true physical strength grow with increase in the magnitude of cold-hardening? This can be answered ~~thus~~ as follows:

The presence of branches CD in the diagram of strength is determined by the structural crystal peculiarities of the composition of the grains of metal. The grains have particular planes--planes of cleavage--appearing in the regions of weakness. Therefore, fractures take place precisely along these planes up to the attainment of a definite critical value of normal stress. The increase in resistance to break with cold-hardening is governed by the pulverizing of the grains, taking place during plastic deformation and clearly detected in breaks at -196°C. A more dispersed structure should have a greater strength according to considerations.

In the first place, as was shown to us earlier,(12) the formation of a brittle crack in the polycrystal specimen takes place not simultaneously, but gradually and by way of interference of the individual elementary cracks, along the grain, equal to the diameter. During decrease in the grains, the elementary cracks decrease and therefore their interference is made more and more difficult (the cracks are weaker) and the macro-fracture fuses into one embryonic crack.

In the second place, insofar as the formation of twins precedes fracture, the pulverization of the grains occurring during the intensification of cold-hardening should lead to the diminution of the twins and consequently should lead to the diminution of the spots of overstrain connected with them, and

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to the distortions in the lattice and hampering of the formation of elementary cracks. Finally, increase in cold-hardening should lead to interweaving of the shears, decrease in lengths of free run of the twins, and increase in resistance to twinning. Everything put together leads to the growth of true physical strength--branches of resistance to break.

From what is stated above, ~~the above stated~~ in full agreement with the ideas of A. V. Stepanov, it simply follows that plastic deformation precedes any fracture. In some cases, when under ~~at~~ given conditions of the experiment it is possible to reach the level of resistance to twinning, the twins accompany the break and the cross-section of the break acquires a "brittle" crystal-shining character. ~~ation~~ In others, when the possibility arises for the development of a displacing plastic deformation, the break takes place from the distortions, made by shears accumulated in great number, and has a dull-fibrous character.

However, the kinetics of crack-formation in both cases should be adequate in principle and always connected with the preliminary occurrence of plastic deformation (twinning or shearing) and by subsequent normal stress action. By the way, in this method it is easy to find the explanation for the diversity of fracture types.

Twinning processes accompany the appearance of very great local distortions, irrational in number, with the distortions from shears. One of the manifestations of unusually great disturbances of normal structural state, created by the twins, is the formation near them of easily-observable pores or canals, which were first discovered by Rose (13) in calcite. These pores, to the distortions in the lattice and hampering of the formation of elementary cracks. Finally, increase in cold-hardening should lead to interweaving of the shears, decrease in lengths of free run of the twins, and increase in resistance to twinning. Everything put together leads to the growth of true physical strength--branches of resistance to break.

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Our assertion about the identity of the mechanism explaining the diagram of strength appears to be particularly convincing in the case of alloyed high-~~strength~~ tensile steel, found in a heat-treated state (tempering plus annealing). Such steels, as is known, during temperature variations in tempering after annealing, attain values of strength corresponding in the two branches of the diagram of strength, to those for pearlite. However, a study of the fracture forms of alloyed steel shows remarkable differences from those of pearlite steels. Namely, fractures corresponding to both branches in the diagram of strength acquire an almost identical form of dull finely-dispersed surfaces. The latter circumstance

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serves as a good confirmation of the correctness of our concept and shows: a) the uniformity of the mechanism of fracture in both branches of the diagram of stability and b) the circumstance that along the ascending line of the diagram of strength (CD) the fracture can take place across the micro-steps, just as along the vertical line (ED).

In the sense that the technical strength is the conditional one in comparison with the true physical strength, the latter can be called conditional in comparison with the theoretical physical strength. However, the degree of conditionality of these two graduations is different.

The fact is that the level of technical strength or macro-strength is quite unstable and can greatly vary depending upon the form of the strained state, test temperature, and rate of load. The true physical strength is more stable and independent of these influences. It can almost be recognized as a constant of the material, describing the upper limit of the stress which the given material is able to withstand without fracture.

During a precise determination of all micro- and macro-parameters and transitional coefficients (which up to now have been almost impossible to determine), one form of strength can be reduced to another.

As it seems to us, the ideas cited above permit one not only to discount the basic proofs of the supporters of the theory of brittle- ductile strengths, but also simultaneously and fairly clearly to show the logical consequences and authenticity of the theory of single strength. Unfortunately it is very difficult

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to conduct conclusive experiments in order to show irrefutably ~~proachaily~~ the physical justification of the theory of normal strength. However, the theory appears to be sufficiently convincing in the present state of affairs ~~things~~.

As is evident from the above~~-stated~~, to improve the diagram of strength as proposed by us is connected primarily with physical peculiarities, microscopy, and with the kinetics of crack-formation during fracture. The macroscopic picture of the examined process having practical significance agrees in greater measure with and is described by the curve of technical strength and therefore satisfies the conceptions of Davidenkov and Fridman, with those certain modifications of which we spoke earlier.

Concluding Remarks

Plastic deformation accomplished by slipping shear or twinning, precedes all fracture. As a result of flow, distortions in the crystal lattice are formed, pre-determining the break (necessary condition). The final factor leading to fracture is the action of normal tensile stress (sufficient condition).

In pearlite steels (with a ferrite base), readily twinning and producing slips across the planes of cleavage, the form of the break obtained is sharply diverse: shining-crystal ("brittle"), and dull-fibrous ("ductile"); nevertheless, fractures take place along the same plan. The formation of individual twins precedes the crystal break and the fibrous are preceded by a great number of successive shears; i. e., in both cases either these or other elements of plastic deformation. In the latter case, the fracture takes place in those areas of crystal badly broken up by the accumulation of shears along the microsteps governed by normal stress action. The appearance of the specific ductile break is due to the small number of steps of break and their closeness and excludes the possibility of observation by ordinary means.

The twins create such sharp distortions in the lattice (micropores or canals), that the break becomes possible after very small total displacements of atomic layers, almost across the sound little-deformed (but badly-displaced) areas. As a result, the cross-section of the break acquires a shining quasi-virginal character.

In high-~~strength~~ tensile alloyed steels, in contrast with the pearlite steels, the breaks corresponding to the two branches of the diagram of strength are obtained quite similarly, according to their external form. Hence the hypothetical conclusion can be made that the presence of two forms of breaks is not the unfailing condition for the formation of two branches in the diagram of strength.

The diagram of strength generally proves to be quite complex. Its complexity consists partially of the fact that the dependence upon the test conditions can reveal the stress values corresponding to some levels of strength; namely to the technical strength and true physical strength. Everyone of these curves, at first glance, has an independent and separate character. However, this is only apparently so, and in reality one curve can be obtained from another by introducing the corresponding correction factors which determine the physical peculiarities of the fracture. At the same time, each of the

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two enumerated curves approaches more and more the third curve of real theoretical strength.

In other words, the curve of technical strength describes the macroscopic side of the phenomenon and has the most conditional character*. The curve of true physical strength is less conditional, but still lags far from the level of true strength.

Thus, the proposed concept implies that fractures due to plastic deformation always take place under the influence of normal tensile stress during its values corresponding to the level CD or DB (dependend upon the conditions of stress and circumstances of the experiment).

By way of introducing the corresponding coefficients, strength CD or DB can theoretically be converted to the real or theoretical strength, distinctive of the given plastic deformation. However, our ignorance of these coefficients does not yet permit us to do this.

At the same time, the accuracy of the curve of technical strength, from the practical point of view, appears to be completely satisfactory and with its help most technical calculations can be performed. However, in applying the idea and meaning of technical strength, it is always necessary to have in mind that conditional (nominal) sense which is inherent in it.

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Submitted to
the Editor
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Footnote*: However, it is more physical than the yield point figuring in the resistance of materials.

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Please consult original document for figures.

FIGURES

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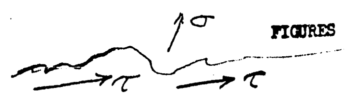
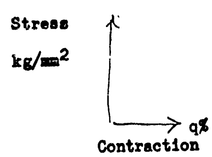


Figure 1. Schematic representation of the steps of rupture, formed during the action of normal stresses along the line of slip (shear).



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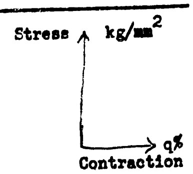

Figure 2. Diagram measuring the brittle resistance to break (tear)--the real physical strength in dependence upon the degree of previous cold work by tension

Figure 3. Diagram demonstrating the interrelation of technical and physical hardness and their variations depending upon cold working.

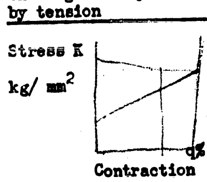

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Figure 4. The probable course of real and theoretical physical hardness during a variation in the degree of previous cold-working.

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